Nb_3Sn Quadrupole Development at Fermilab

Alexander Zlobin

Technical Division

Fermilab

Introduction

Fermilab is developing a new generation of accelerator magnets based on Nb_3Sn superconductor - High Field Magnet (HFM) program

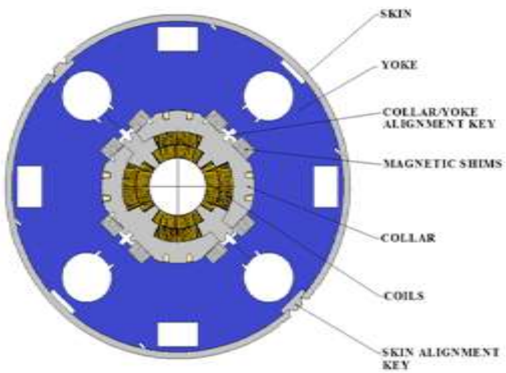
- **LHC luminosity upgrade**
- **Muon Collider Storage Ring**

New recent results

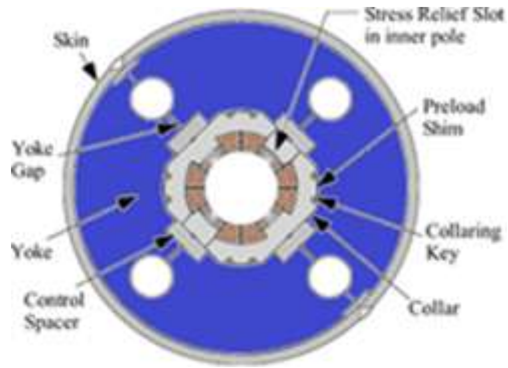
- **Assembly and test of the 2nd Nb_3Sn quadrupole model (TQC03E) with RRP-108/127 strand, dipole style collar and coil alignment**
- **Test of 4 m long Nb_3Sn quadrupole coil in a quadrupole mirror structure**

This work was performed in support of US-LARP

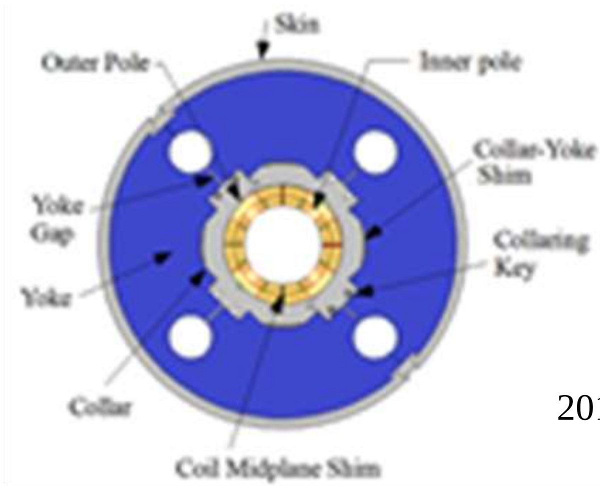
TQC Model Design



LHC MQXB
70 mm NbTi quadrupole

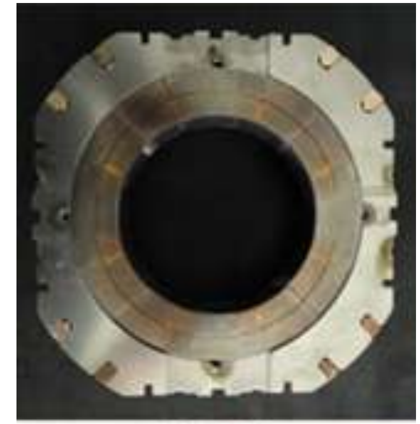


2005



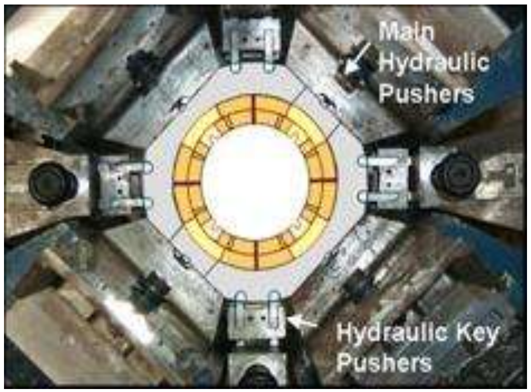
2010

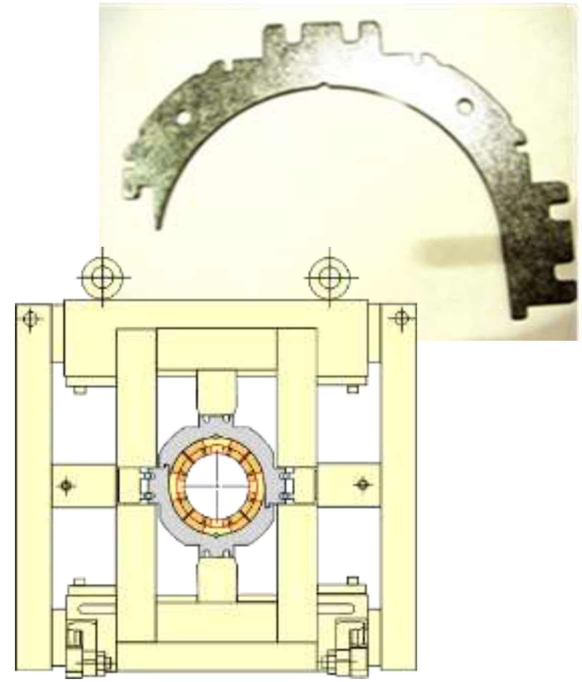
TQC
90 mm Nb_3Sn quadrupole

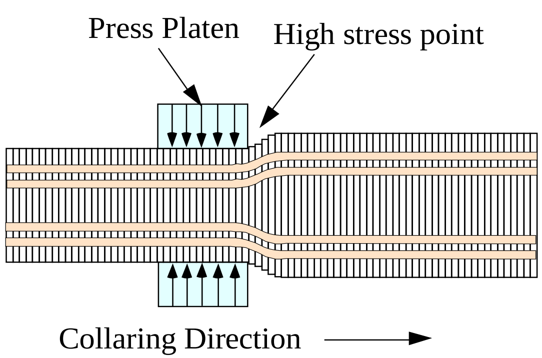


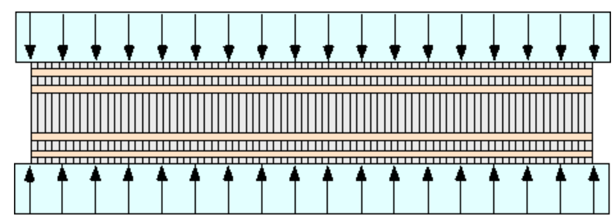
- **TQC: 90 mm two-layer coil, 27-strand cable**
- **Mechanical structure: modified MQXB**

Quadrupole Coil Collaring









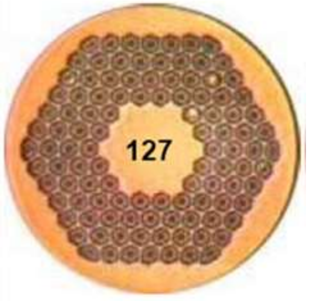
Collared in one step

- **Time consuming process for Nb_3Sn magnets with many (~6-8) passes and some risk of damage to coils**
- **Collaring with a single pass reducing coil degradation risks and construction time (<1 week)**

Design Features and Test Objectives

Model	Strand		Coils	Collar	Coil prestress, MPa
	design	D_{eff}, um			
TQC02Ea	RRP-54/61	~60-70	**20**,21,22,23	Q	-112
TQC02Eb			20,22,23,**28**	D	-124
TQC03E	RRP-108/127	~40-50	30,31,32,33	D	-124

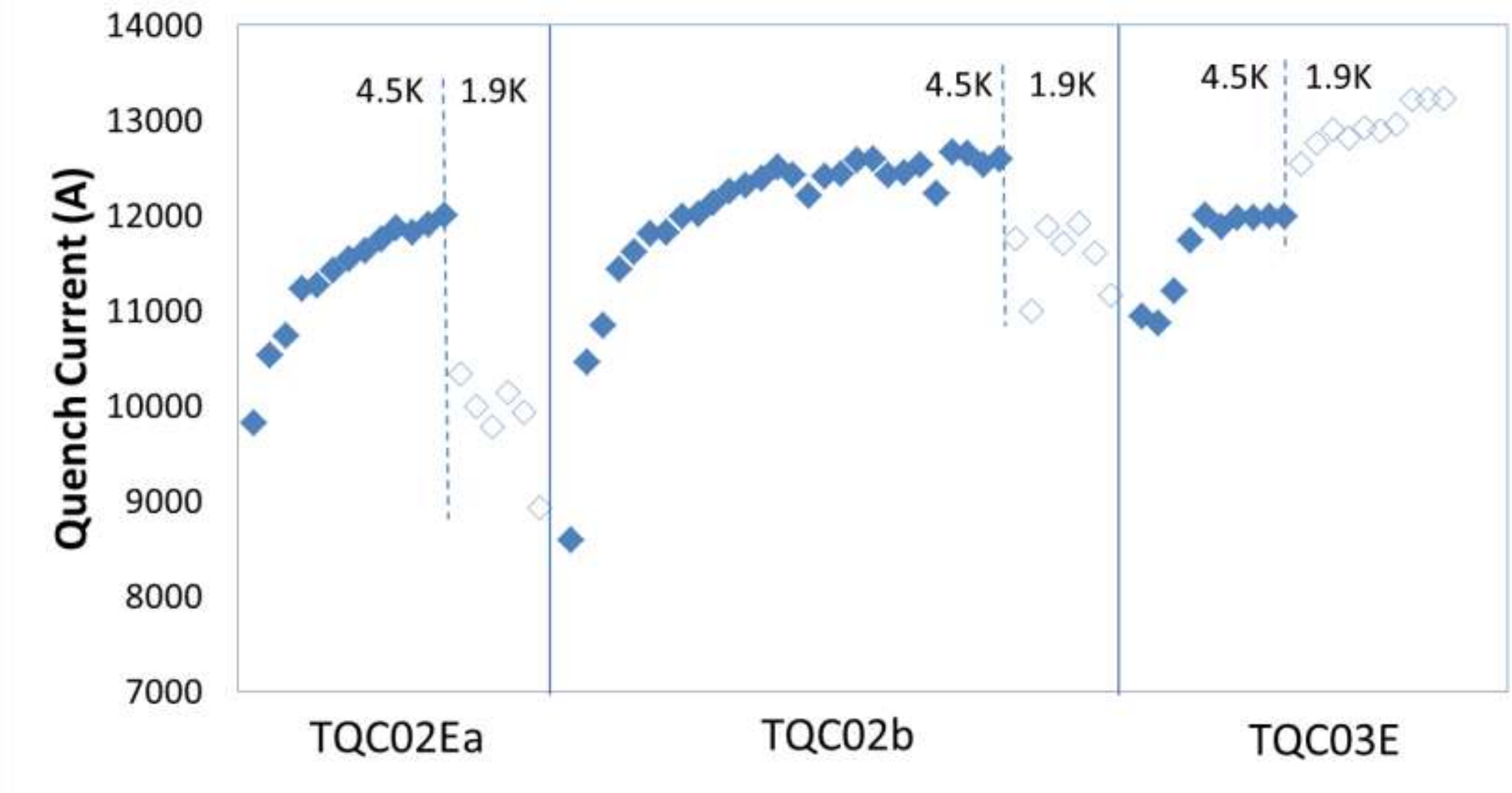
All coils were fabricated by FNAL/LBNL and previously tested in LARP TQS models



Objectives

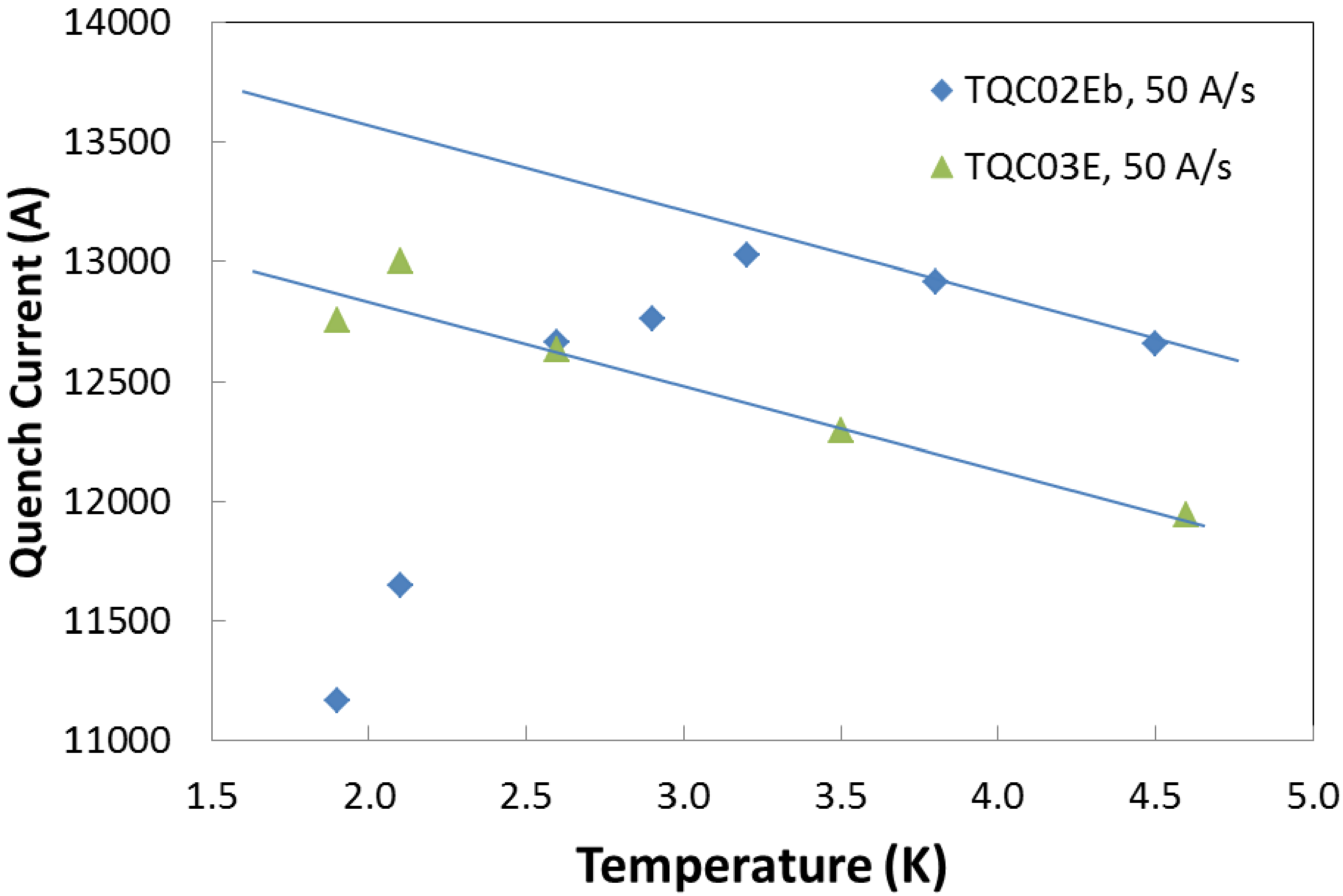
- ❖ **RRP-54/61 vs. RRP-108/127**
- ❖ **D-style collar vs. Q-style collar**
- ❖ **Performance reproducibility**
  - o **Quench performance**
  - o **Field quality**

Quench Training



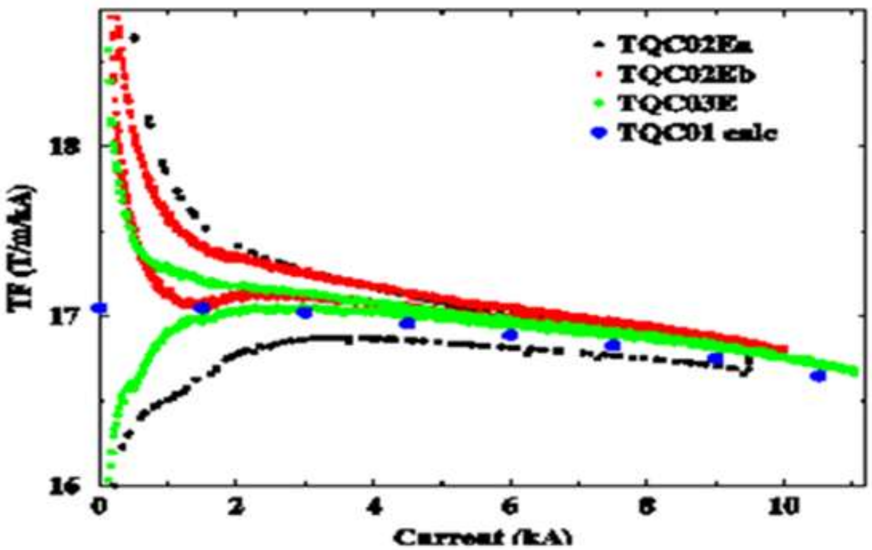
- **Similar quench performance for Q and D collar structures**
- **All magnets reached their conductor limit**
- **Stable performance with RRP-108/127 strand at 4.5 and 1.9 K**
- **Multiple coil handling and test cycles => robust technology**

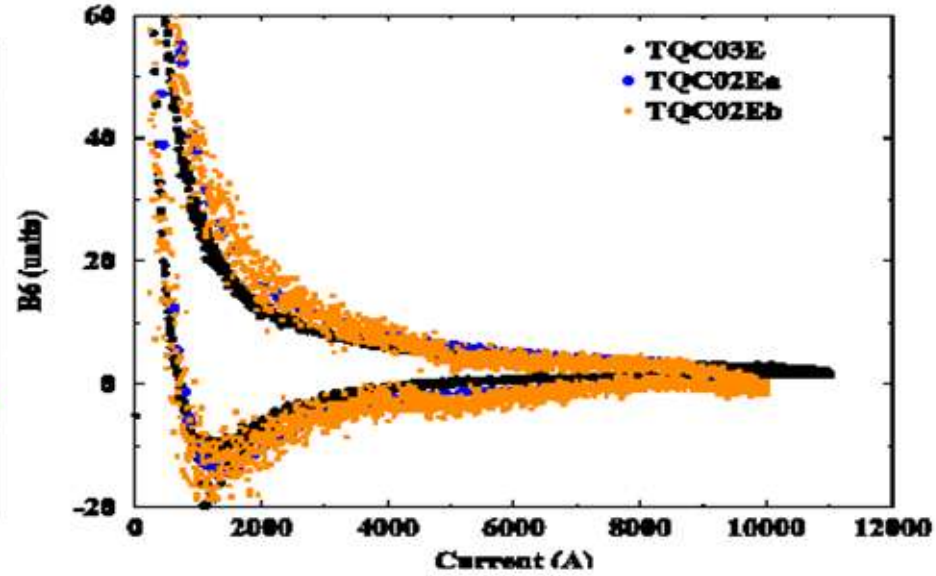
Temperature Dependence



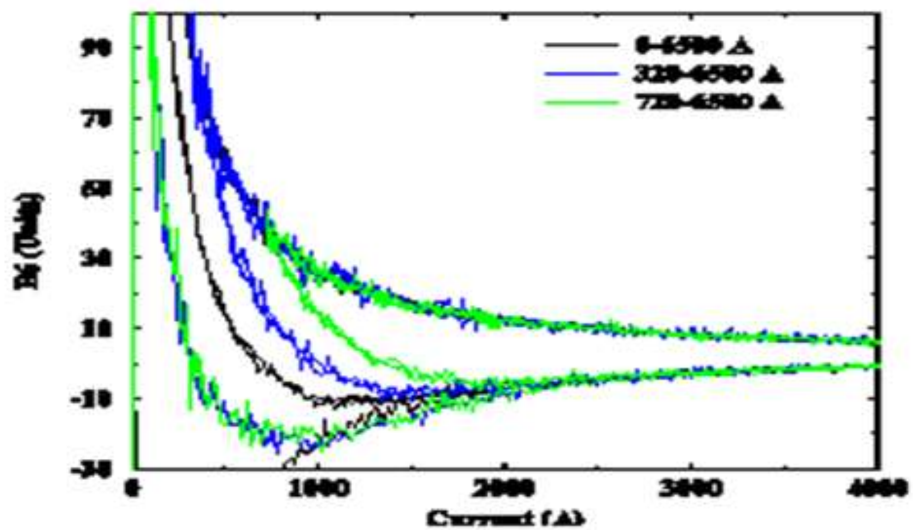
- **TQC02Eb**: **"Flux jump" instabilities at T<3.5 K**
- **TQC03E**: **stable performance at all temperatures**

Magnetic Measurements





- **Iron saturation effect is small and consistent with calculations (TF and b_6)**
- **Coil magnetization is large in Nb_3Sn magnets due to high J_c and large D_{eff}**
    - **Smaller D_{eff} => smaller hysteresis**
    - **Cycle optimization**

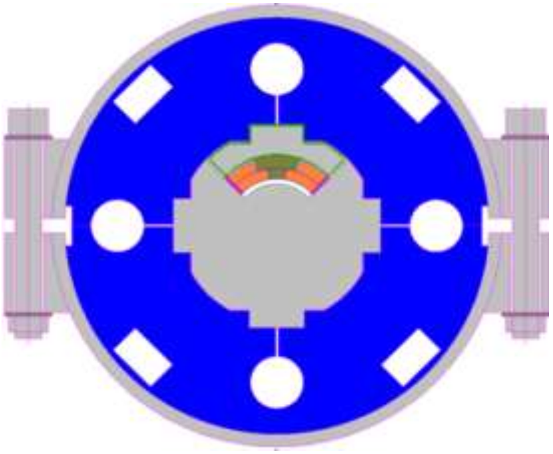


Field Harmonics

n	b_n			a_n		
	02Ea	02Eb	03E	02Ea	02Eb	03E
3	-2.56	-3.57	-0.5	1.72	4.71	-2.64
4	-1.65	-3.34	0.19	-2.7	-0.29	-2.81
5	0.72	0.20	-0.03	1.61	-0.76	2.21
6	-0.96	-0.62	0.72	0.59	0.05	-0.36
7	-0.34	0.03	-0.06	-0.32	0.10	0.18
8	0.14	-0.07	-0.06	-0.07	0.01	-0.08
9	0.06	0.06	0.14	0.12	-0.02	0.01
10	-0.08	0.01	-0.02	-0.01	0.02	0.08

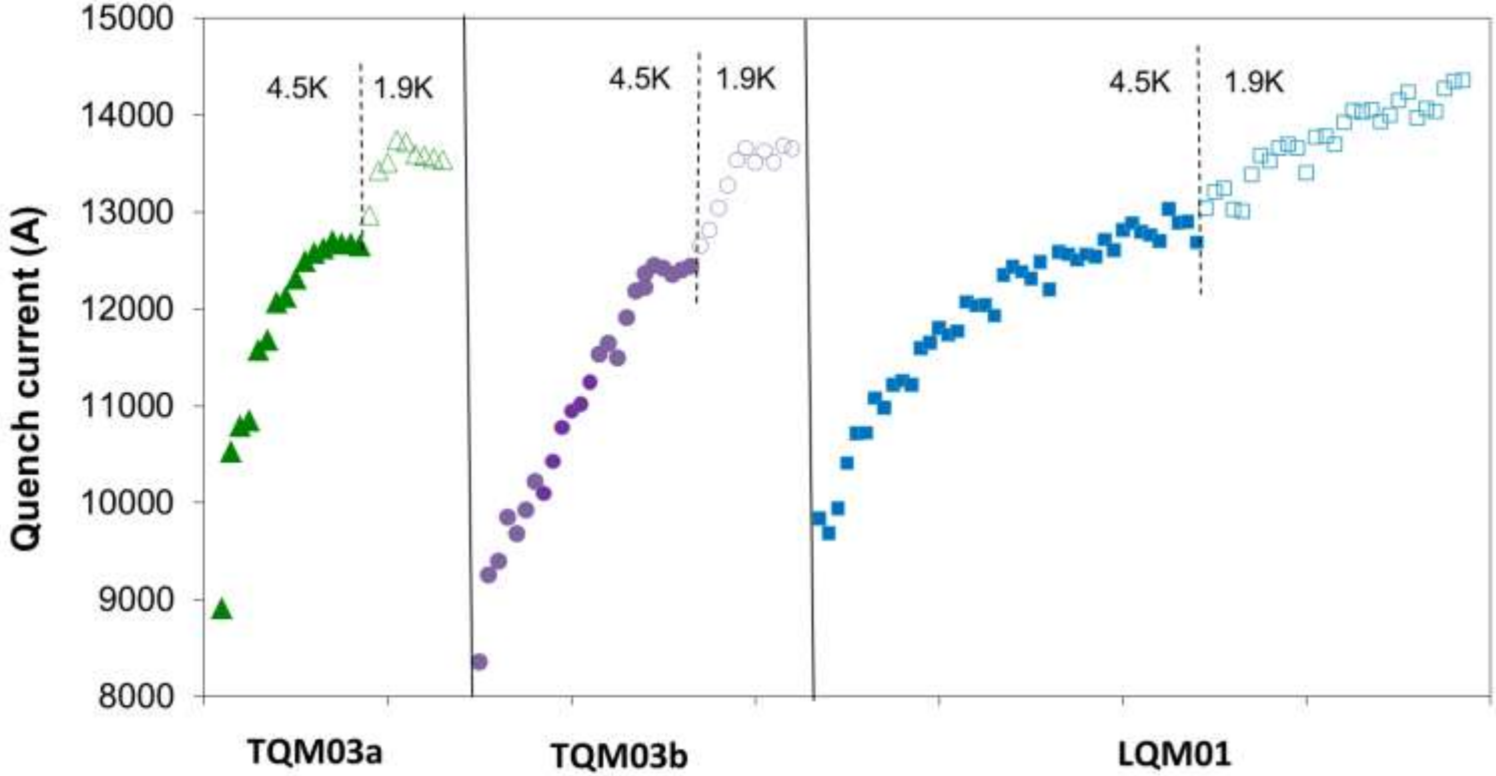
Low, reproducible field harmonics

4 m Long Coil Test



- **Objectives:**
  - **90-mm Nb_3Sn coil technology scale up**
- **Quadrupole mirror based on TQC quadrupole structure**
  - **Field and force level and distribution similar to real quadrupole**
- **Quadrupole coil made of RRP-114/127 Nb_3Sn strand**
  - **Cable was fabricated at FNAL**

LQM01 Training



- **TQM: 1 m long quadrupole mirror**
- **LQM: 4 m long quadrupole mirror**
- **Cable and coils were fabricated at Fermilab**

All coils reached their SSL at both 4.5 and 1.9 K

Conclusions

- **RRP-108/127 strand demonstrated stable performance at both 4.5 and 1.9 K => this strand replaces RRP-54/61 strand as a baseline conductor for Nb_3Sn magnets in U.S.**
  - **Strand was developed by FNAL/OST collaboration**
- **Dipole style collar design and collaring process were successfully tested at Fermilab using 90-mm Nb_3Sn TQ coils**
  - **More efficient, less risky process**
  - **Quench performance and field quality are consistent with the test results for models based on the traditional quadrupole collar structure**
  - **Dipole style collar structure can be easily adopted for long Nb_3Sn quadrupole (and dipole) magnets => important for LARP and LHC upgrade needs**
- **90-mm quadrupoles of TQC series developed at Fermilab have all features of accelerator magnet and could be considered for use in real machines**
  - **G_{max}=220 T/m (B_{max}~12 T) => higher with better conductor**
  - **Good, reproducible quench performance and field quality**
  - **Scalable length**